

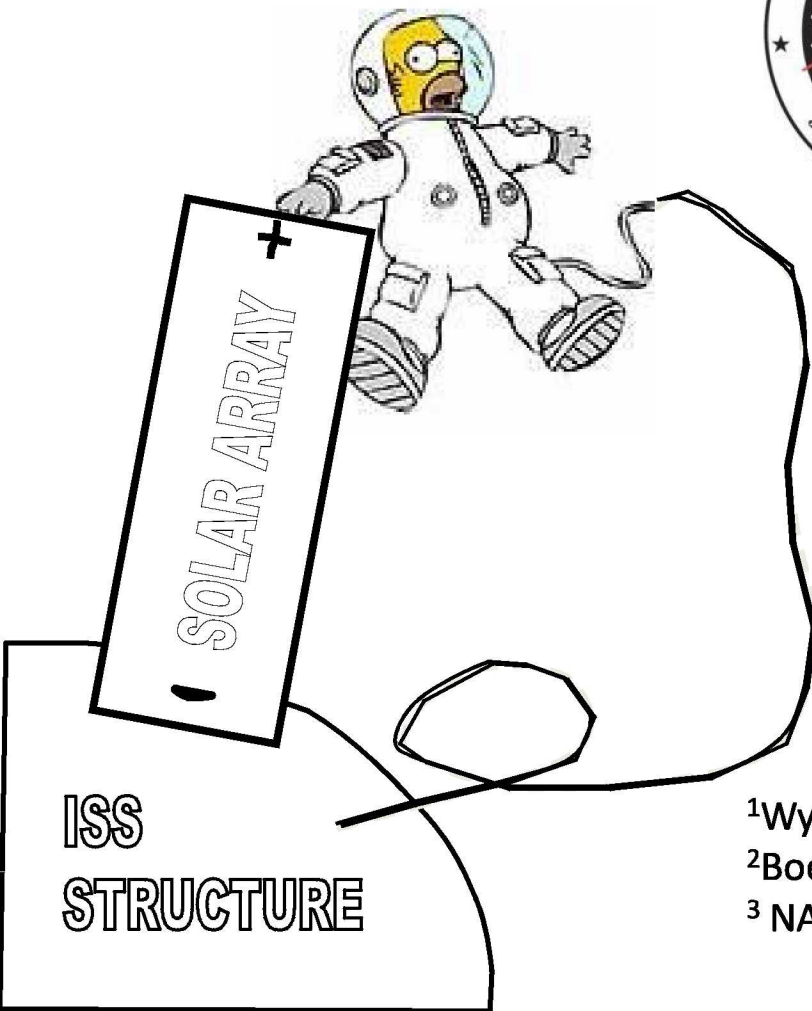
Space Life Sciences Directorate's Position on the Physiological Effects of Exposing the Crewmember to Low-Voltage Electrical Hazards during Extravehicular Activity



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Phoenix, Arizona



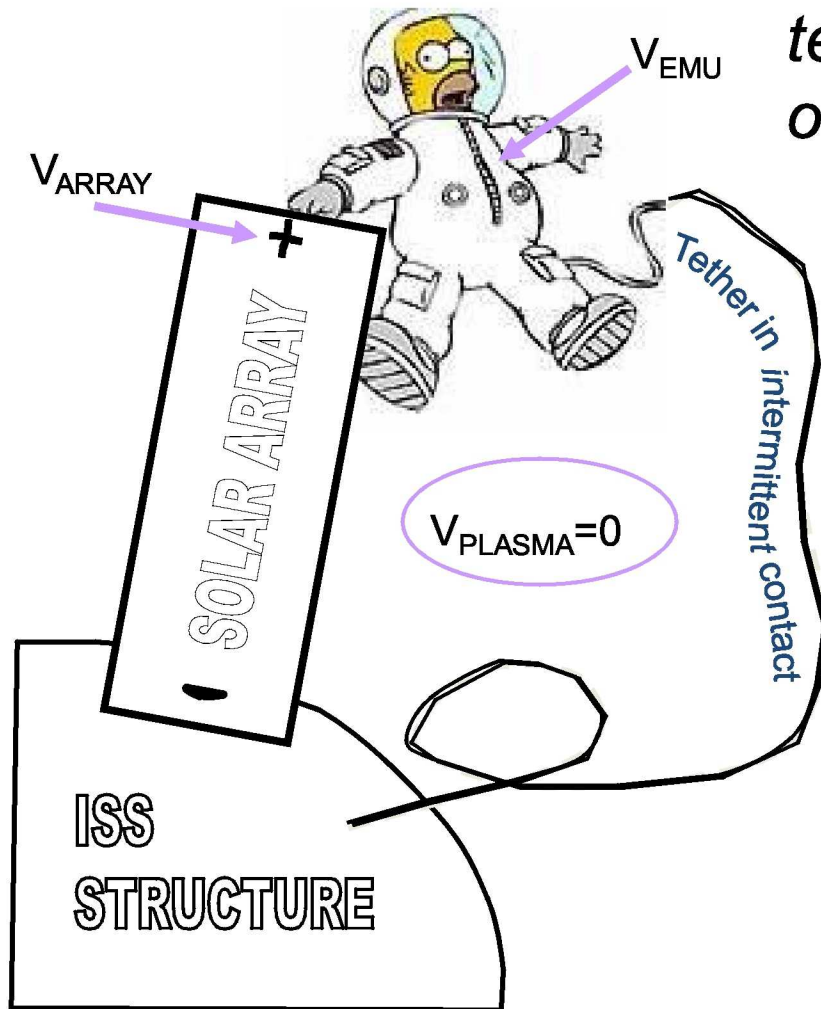
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The Issue

Suppose EVA crew person comes in contact with positive terminal of the solar array or outside of the truss.



- ❑ Does the FUHZ SHUV BODY charge and how long will it take?
- ❑ What electrical currents occur?
- ❑ Can his EMU arc to the plasma?
- ❑ What happens when he finally comes in contact with ISS structure?

In the scenario at left, the EMU in contact with the positive terminal of the array results in electrical potentials arranged so that:

$$V_{ARRAY} > V_{EMU} > V_{PLASMA}$$

Is touching the Space
Station as safe as a
3% LUG RQ D :LUH' R
it a new EVA hazard?



PLASMA FOR DUMMIES



When the thermal energy in a material is so low that rigid bonds between atoms occur, solids form.



Liquids form when the thermal energy is too high to allow rigid bonds, but still low enough that the atoms stick to each.



Gases form when the thermal energy is high enough that the atoms no longer stick at all, for then individual molecules are set free to fill an enclosure.



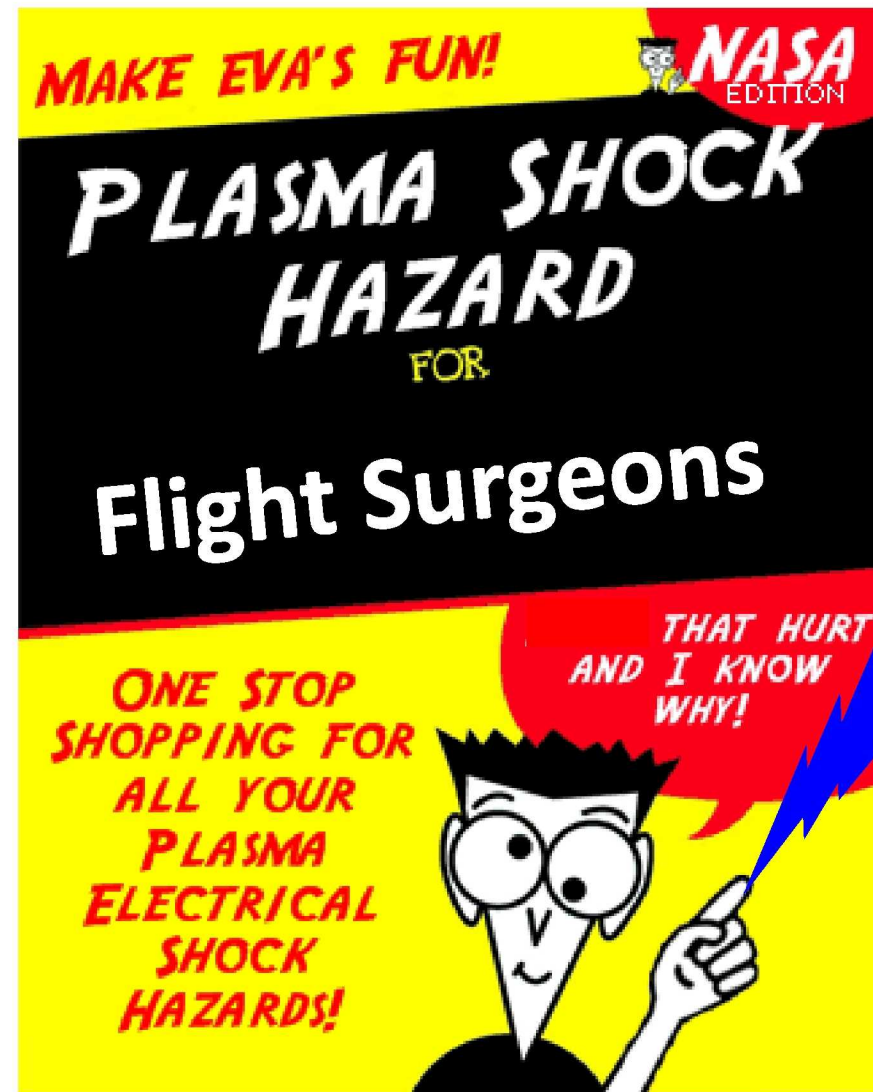
Raise the temperature still further and the molecules fly apart into free ions and electrons forming a fourth gaseous state of matter known as a **plasma**.



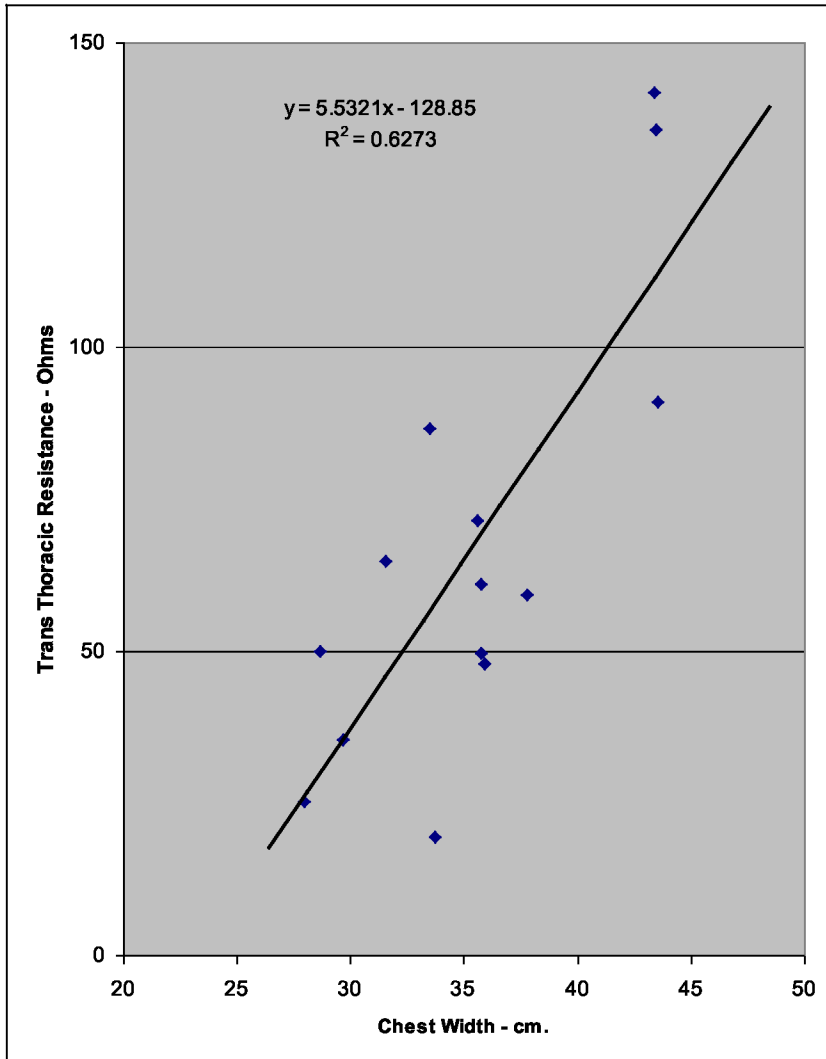
The **new feature of this fourth state** that makes it so different from an ordinary gas is that it **conducts electricity!**

The Problem

- ❑ Space vehicle charging could pose the following catastrophic shock hazards during Extravehicular Activity (EVA):
 1. Electric shock event resulting from a violation of the -40V Floating Potential – charging control required during EVA (previously present at AsMA)
 2. Exposed positive or negative power system wire (new hazard)
 3. Magnetic induction potentials during the EVAs could expose the crew member to positive potentials on many parts of the space suit (new hazard)
- ❑ A crewmember touching a positively charged surface was thought to be galvanically isolated from the vehicle ground – analogous to a “bird on a high voltage power wire.”
- ❑ Recent analysis confirms for positive floating potentials, ionospheric currents to EVA suit can be hazardous; i.e., the “bird-on-wire analysis” is wrong in that the ionospheric plasma itself can close the circuit.



Trans-Thoracic Resistance



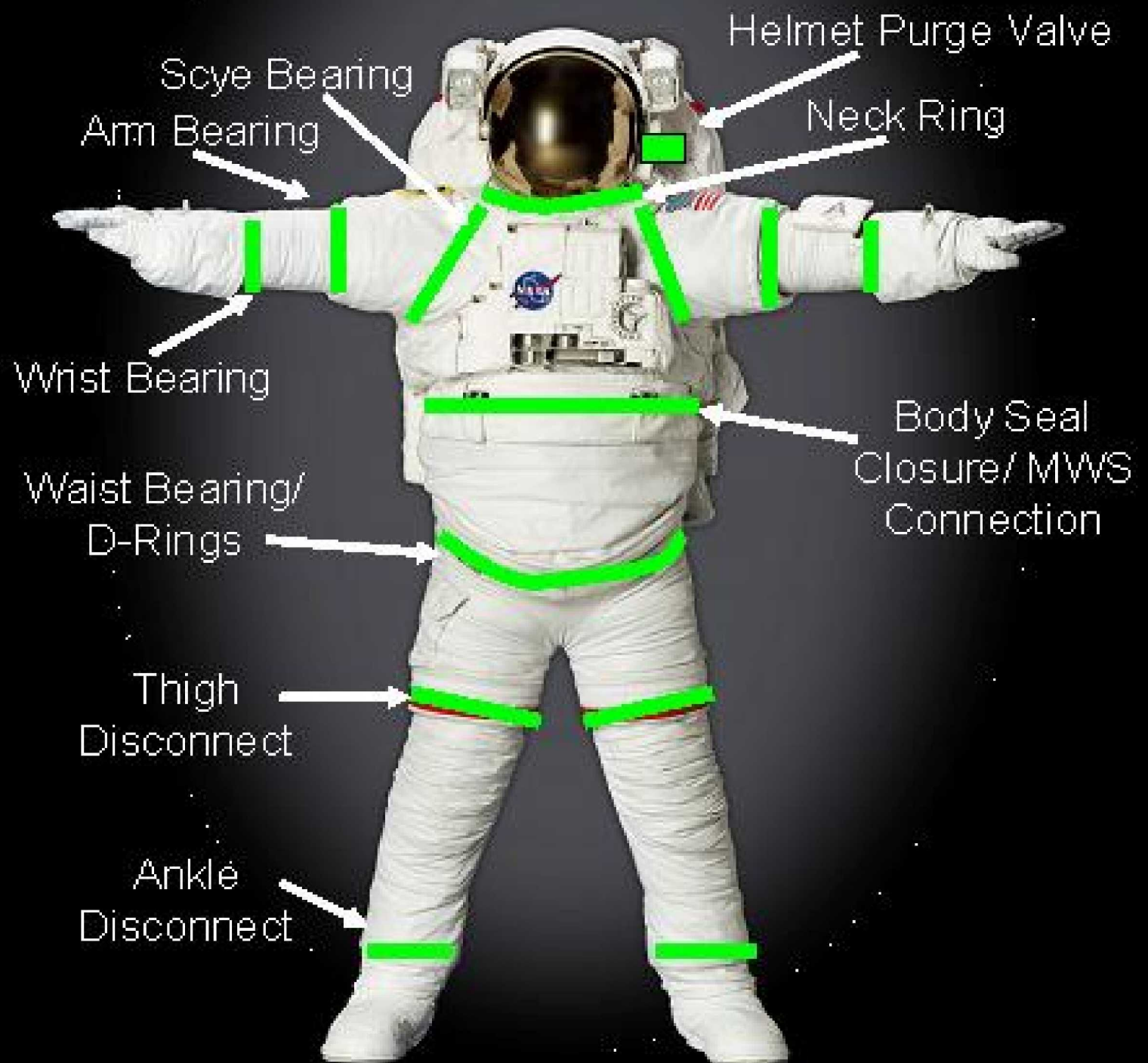
Medical Operations

UHFRRPPHQGV □ WKKDMS □ Base □

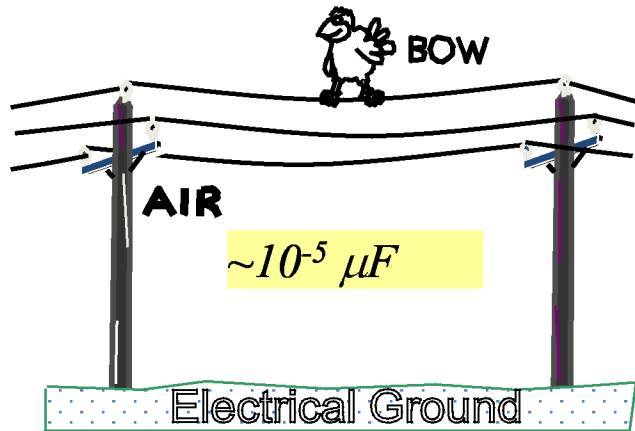
trans-thoracic impedance value
be used for a model in anyone
being exposed to a vehicle
discharge model (NASA STD
3000)

AAMI Standards call for
defibrillator testing to be
conducted using a patient skin-
electrode impedance as low as
25 Ω (ANSI/AAMI DF-2 and DF-39)

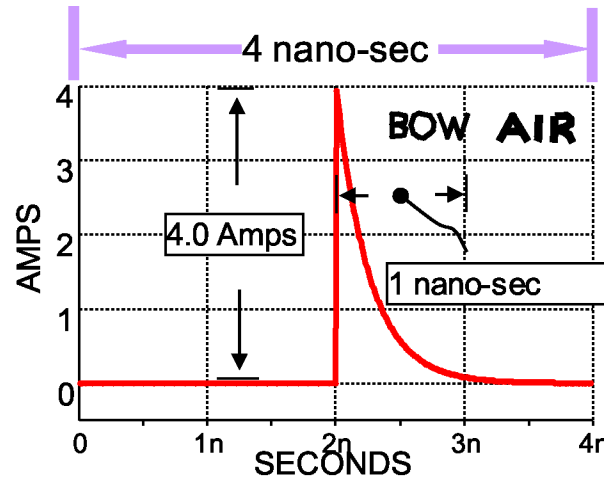
Kerber et al Circulation 63(1)
676 - 682



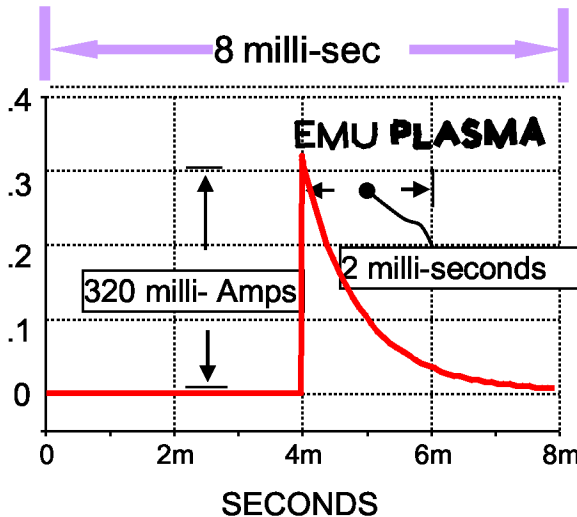
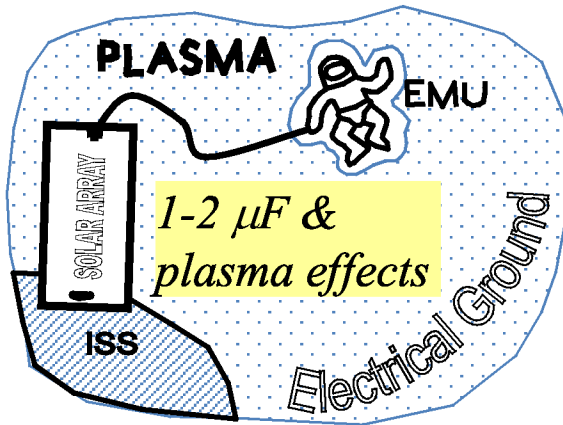
Current Traces for Contact with Charged Wire



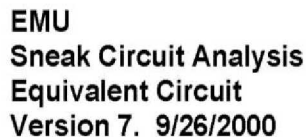
These are modeling results for initial contact with 100 Volt DC source charging through a 25Ω resistance..



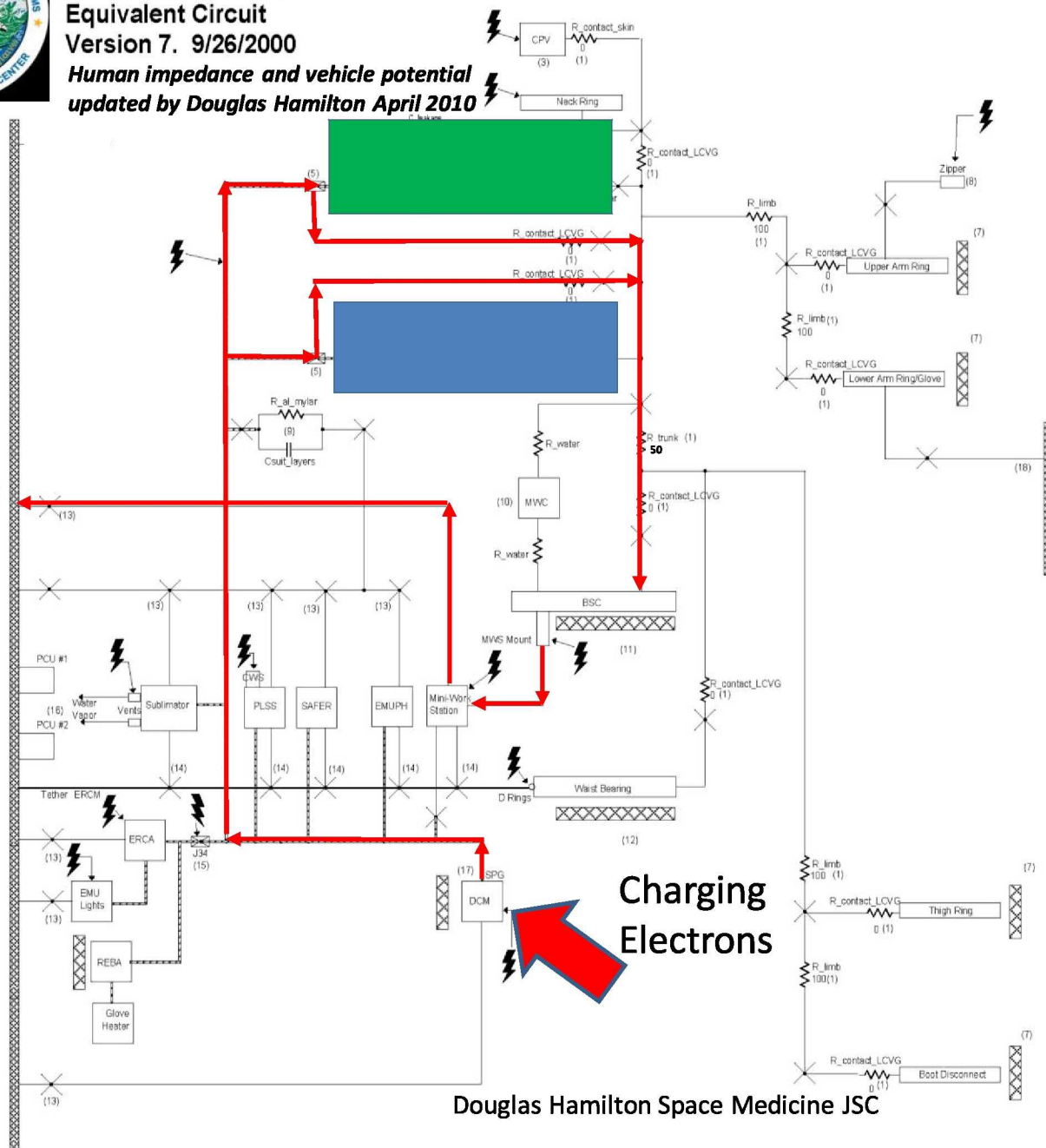
- The current experienced by the bird is:
 - ▶ A nano-second (microwave scale) pulse.
 - ▶ a negligible physiologic event (according to Med Ops.)



- The current experienced by the EMU is limited by the ability of the suit to collect ions:
 - ▶ A few tenths of a milli-second pulse.
 - ▶ Med Ops assessment is that these are significant hazards.



+15 Volts



1. Body model: 100 ohms trunk; 200 limbs.
Skin contact = 0 ohms due to sweat soaked LCVG.
2. For a substituted arc > 1A. Up to 7A is < 1s
3. CPV discharge through contact with CM head.
Contact is random. External metal is exposed.
4. CCA is xfrm isolated so only R_{leakage} and C_{leakage} are issues, need values but guess that R_{leakage} >> 1Meg
ST103 --- one earthplane failed due to internal water.
5. CCA connector is isolated --- new design is grounded.
OBS connector is grounded to SPG.
Both have sweat soaked LCVG connections between SPG and CM.
6. 15.2k is max resistance with FET failure.
Rprobe total = 175 ohms
7. TMG covers upper and lower wings, arms and legs.
Assuming no ARC is covered with TMG (TBD)
8. Upper expander Zipper is exposed.
Assume random contact.
9. Random contact of TMG at cutouts due to al mylar.
C suit is insignificant, R suit should be low << 100 ohms.
10. LCVG water leak between body and metallic surfaces.
The have been 6 such leaks since 1991, mostly at the MMC
11. TMG covers BSC except for MWS mounts.
12. TMG covers wristbearing except at D rings.
13. MWS direct contact to BSC, random contact to station bare metal, random connection to tether, random connection via tools to DCM and SPG
14. Direct contact of any SPG to station FF
15. REBA covered with TMG except J34.
16. Sublimator water into PCU's
17. EMU 151,152 hammer contact to PLSS
SPG is inside DCM, 117V referenced to SPG.
18. Glove tether can hit station

 This symbol means a random connection

 This symbol means discharge to plasma

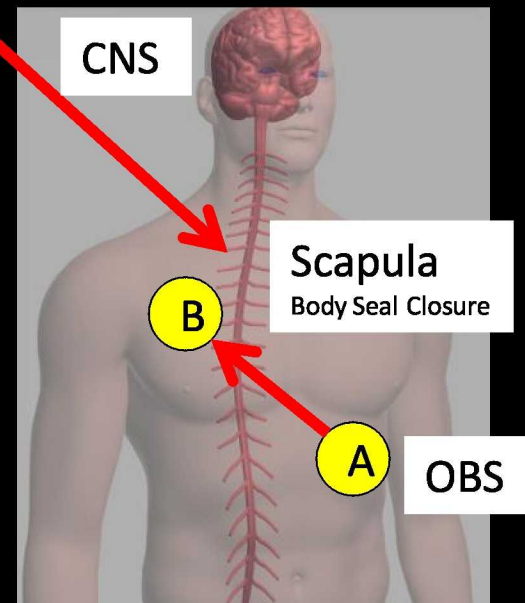
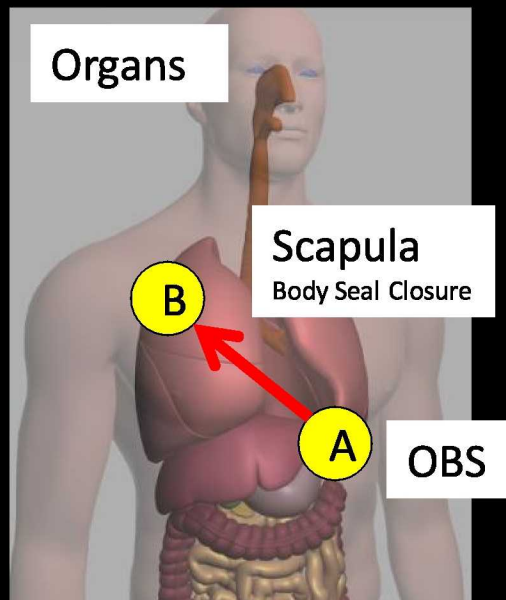
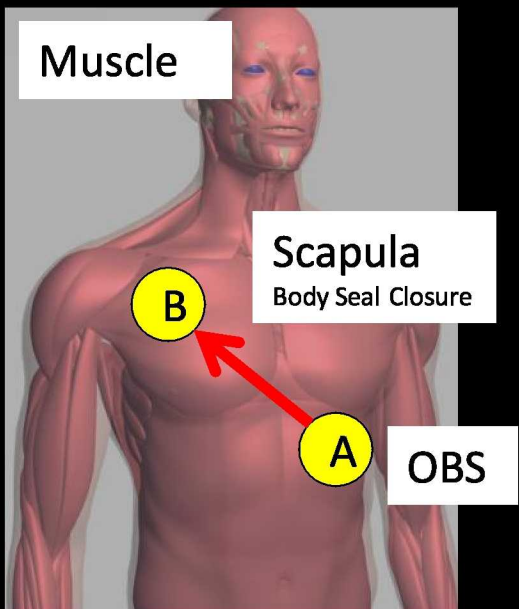
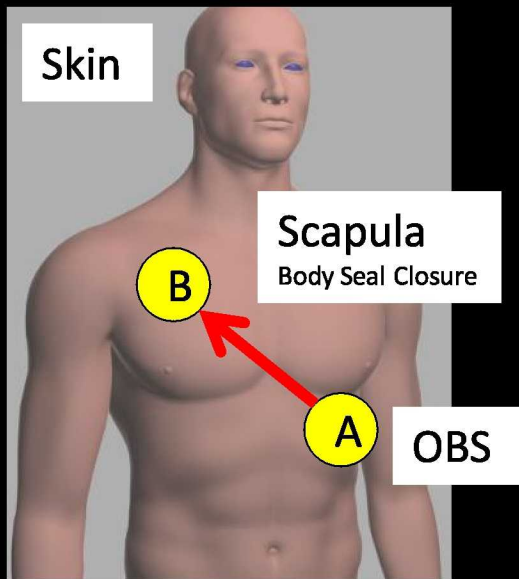
 This symbol is covered by TMG

This symbol means connected to the single point ground (SPG)

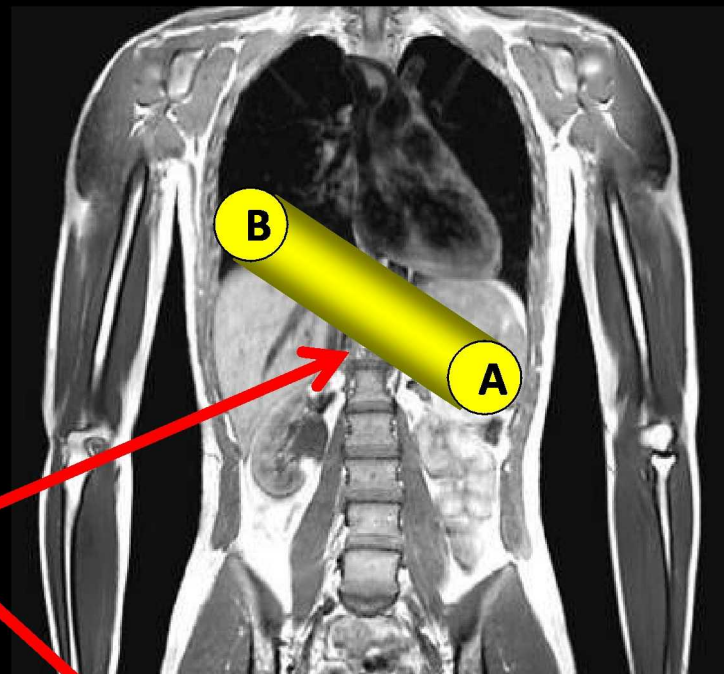
 This symbol is an exposed connector

Douglas Hamilton Space Medicine JSC

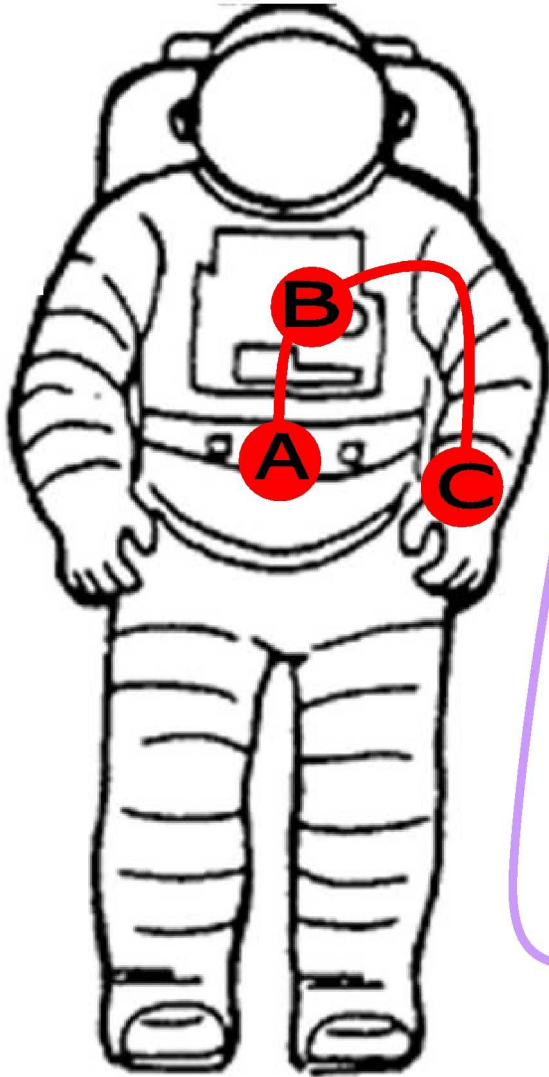
Worst Case Current Path



Spinal cord



Body Impedance used in the Plasma Model

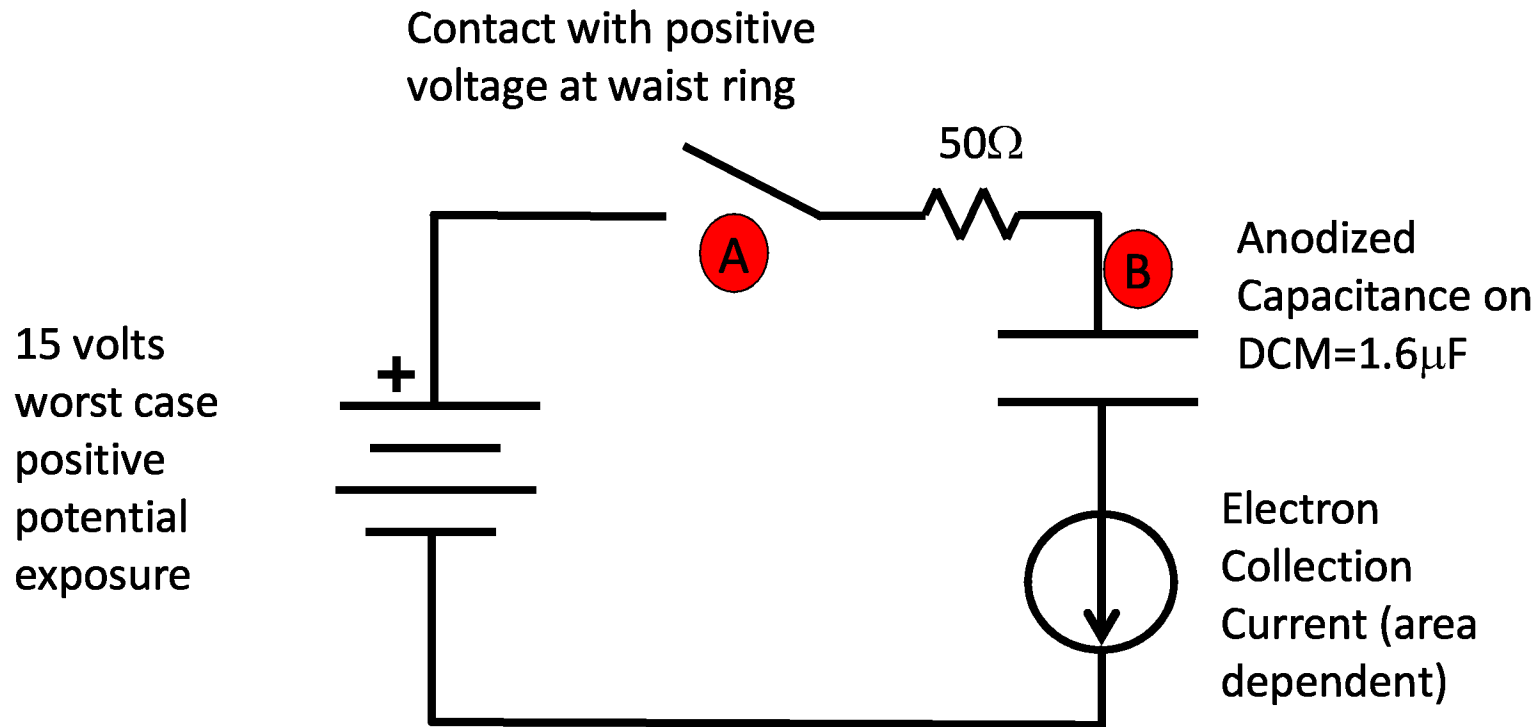


Node	Name
A	D-Ring
B	MMWS,
C	Wrist Ring

Approximate Impedance for paths connecting nodes that collect electrons with nodes that contact ISS ground.				
		Collect Electrons		
		A 0.3m ²	B 0.8m ²	C 0.3m ²
Ground Structure Contact	A		50Ω	550Ω
	B	50Ω		500Ω
	C	550Ω	500Ω	

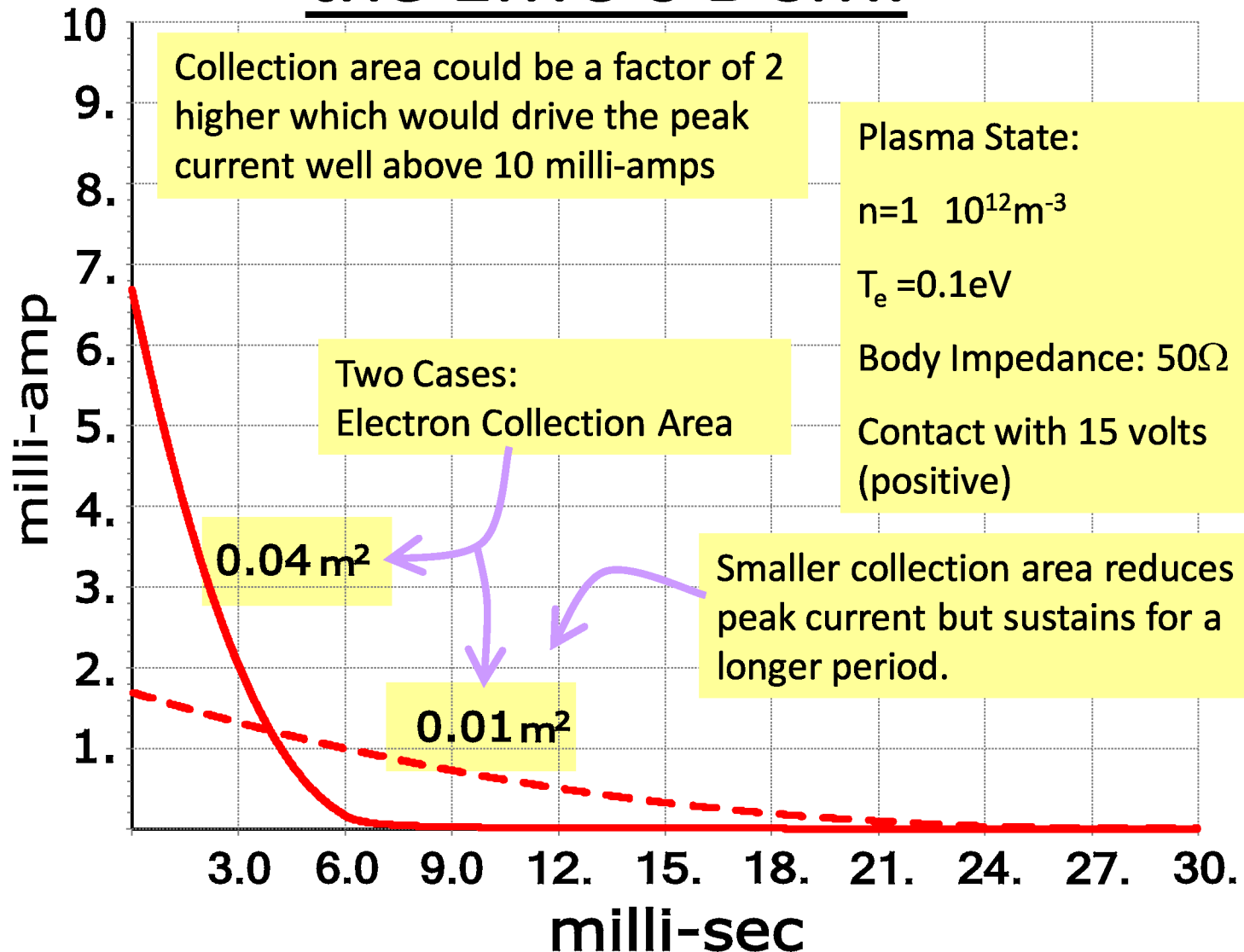
The DCM is located at B -- same contact point to crewmember as the MMWS. Therefore, A to B is the worst-case impedance: 50Ω.

Equivalent Circuit: Waist to DCM (A to B)

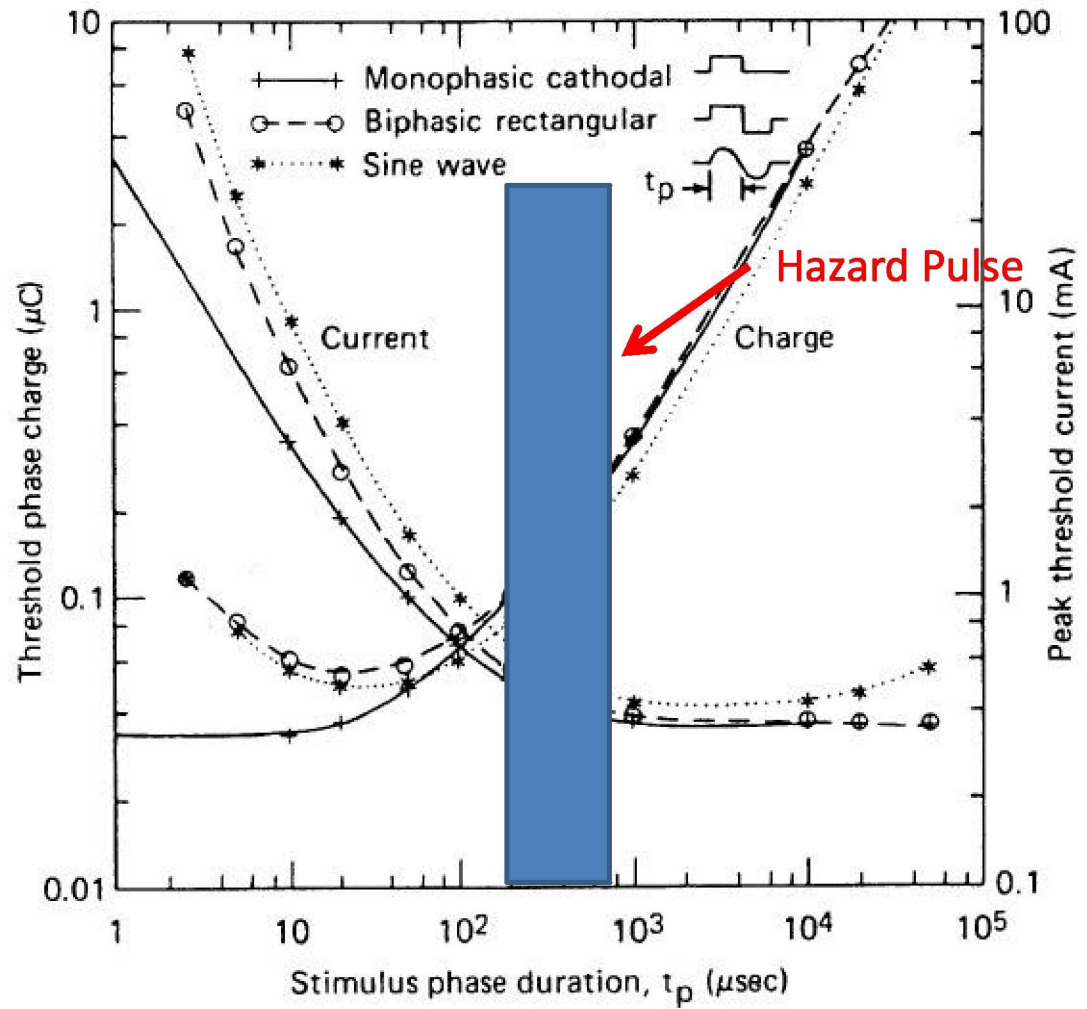


Electron collection is over the anodized material, area assumed 0.04m² (20 cm. square). Smaller collection area of 0.01m² also calculated

Transient current through capacitor on the EMU's DCM.

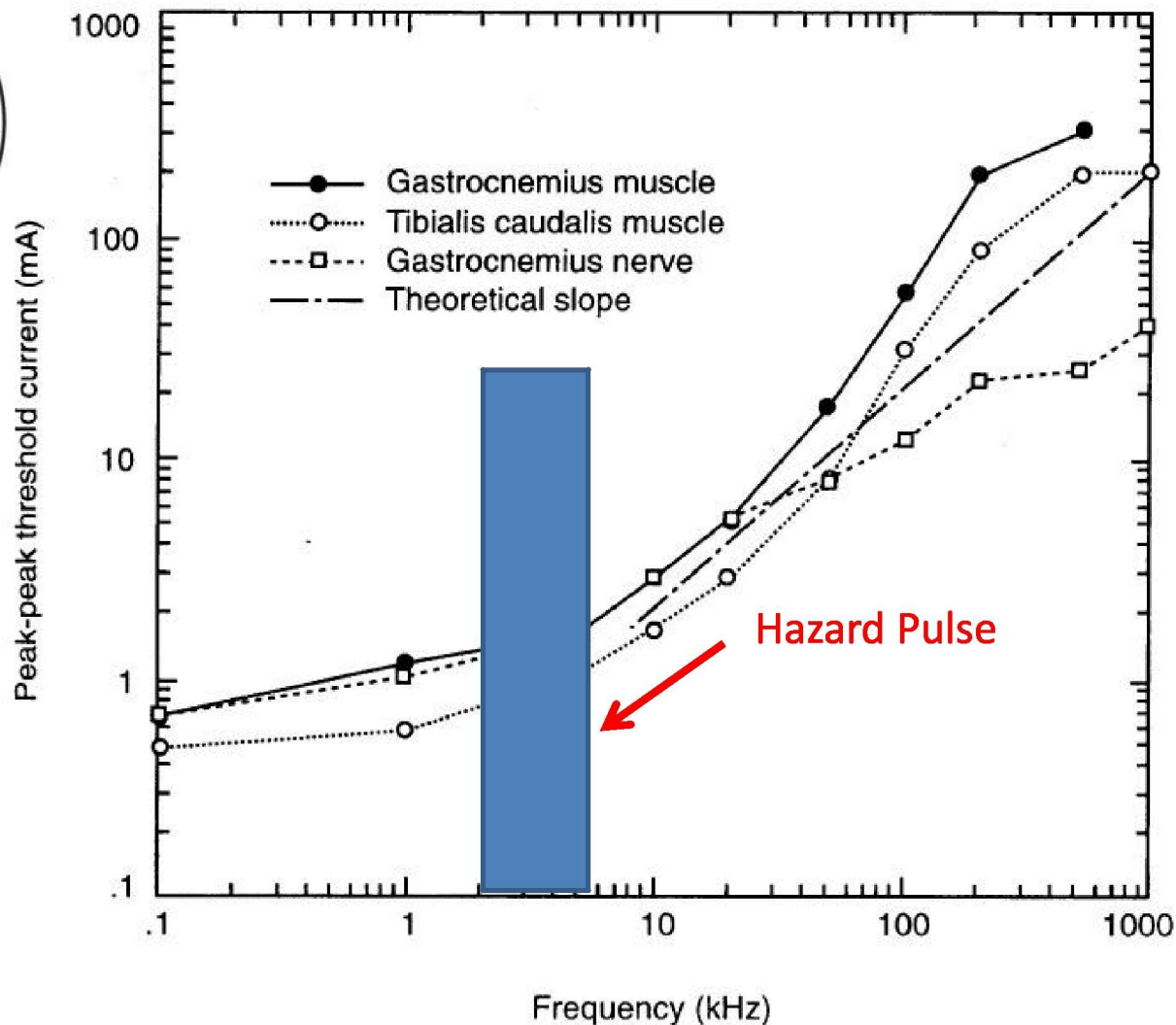


Strength duration relationships derived from the myelinated nerve model



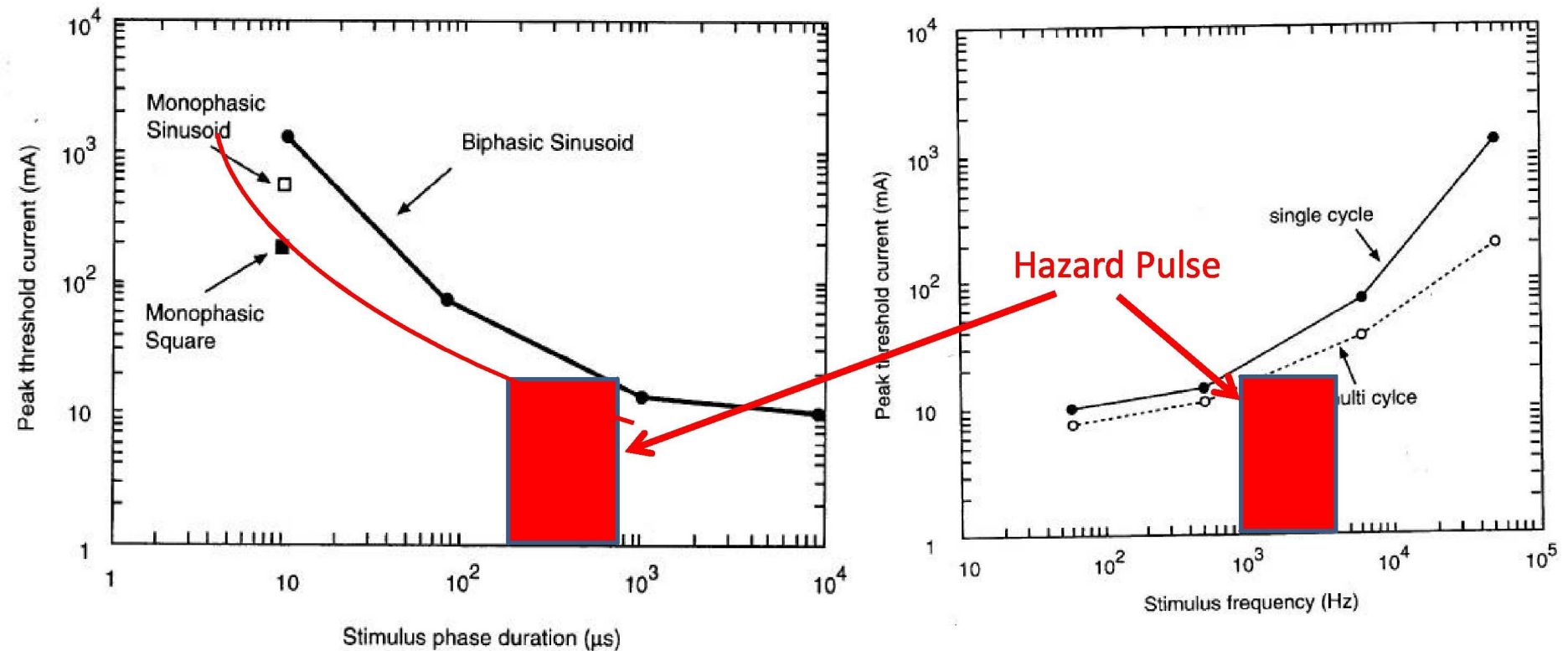
Strength duration relationships derived from the myelinated nerve model: current thresholds and charge thresholds for single-pulse monophasic and single-cycle biphasic stimuli on 20 μm fiber. (From Reilly et al 1985)

Excitation thresholds with sinusoidal current





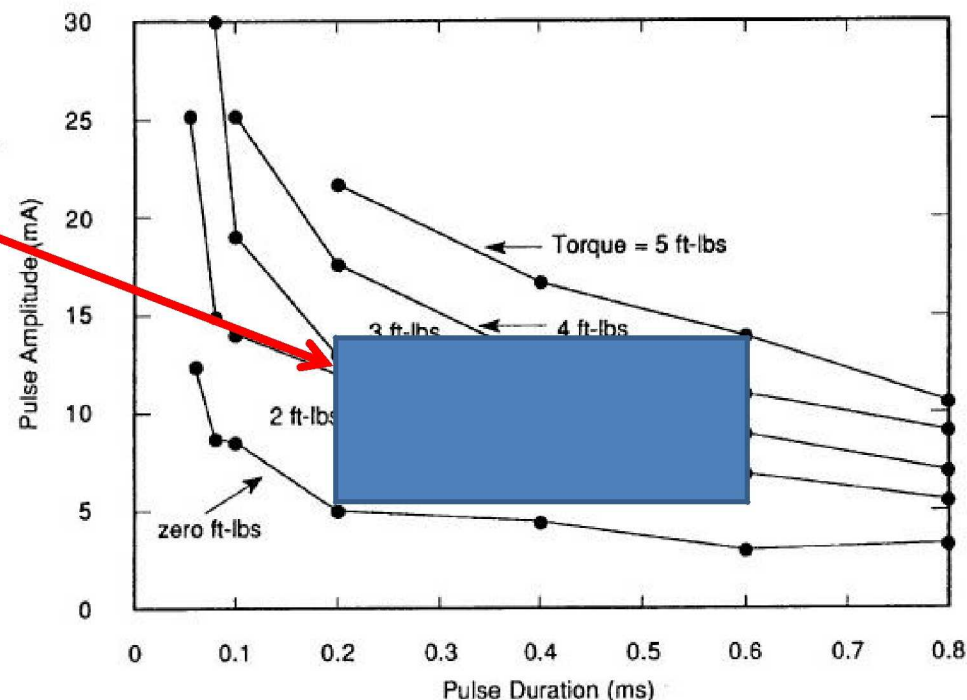
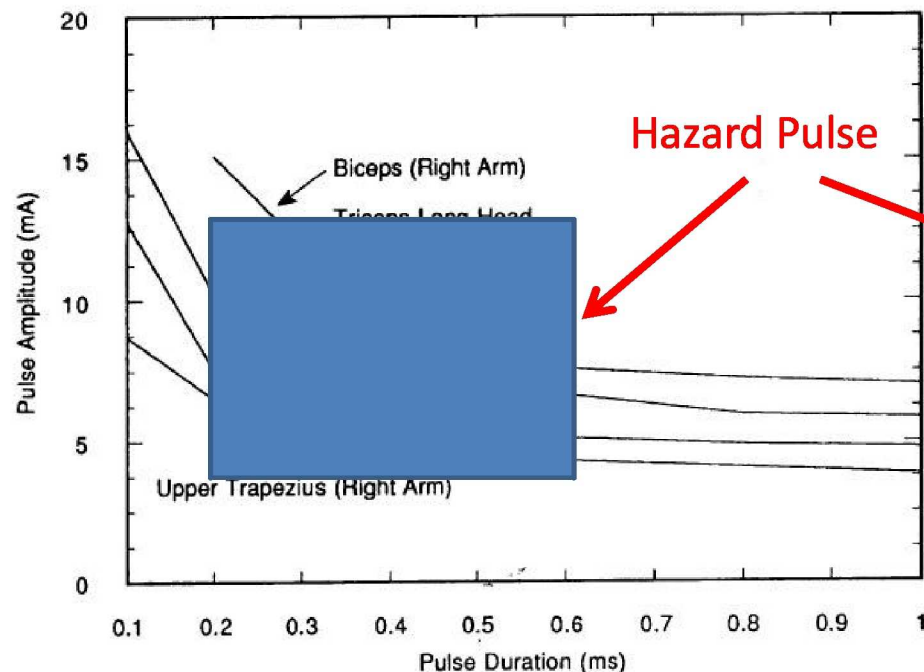
Strength-duration curves for dairy cows



Strength duration thresholds for dairy cows (From Reinemann et al 1996)

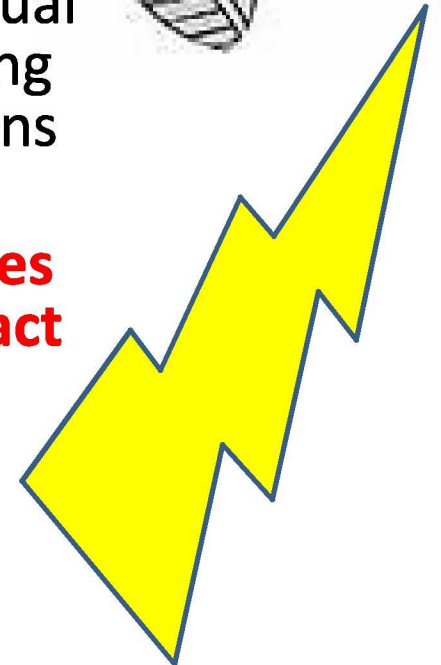
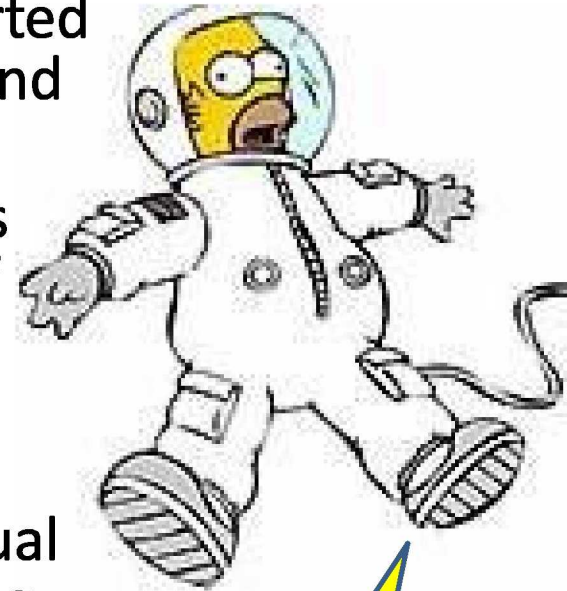


Strength-duration curves for C3 level spinal cord injured patient



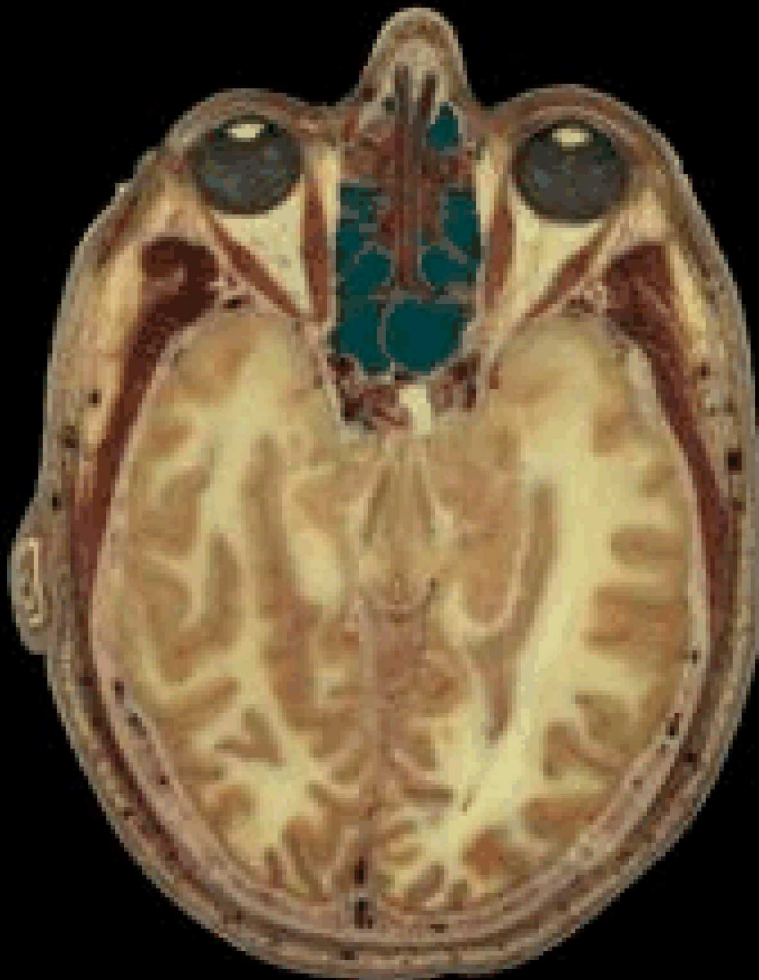
Space Medicine Position

- Anodized areas could be twice as large as reported resulting in currents in excess of 12 milliamps and approximately 600 microseconds duration.
- Fault currents could involve the central nervous system and cause activation of large bundles of motor and sensory nerves resulting in extreme pain and involuntary limb movement.
- Fault currents could involve the peripheral nervous system and cause activation of individual muscle motor units and sensory nerves resulting in startled reactions from unexpected sensations and involuntary muscle contractions.
- **HOWEVER...These are LOW VOLTAGE exposures and, therefore, the large surface area of contact needed to create currents similar to voltage exposures may have electric fields intensities that are not physiologically significant.**



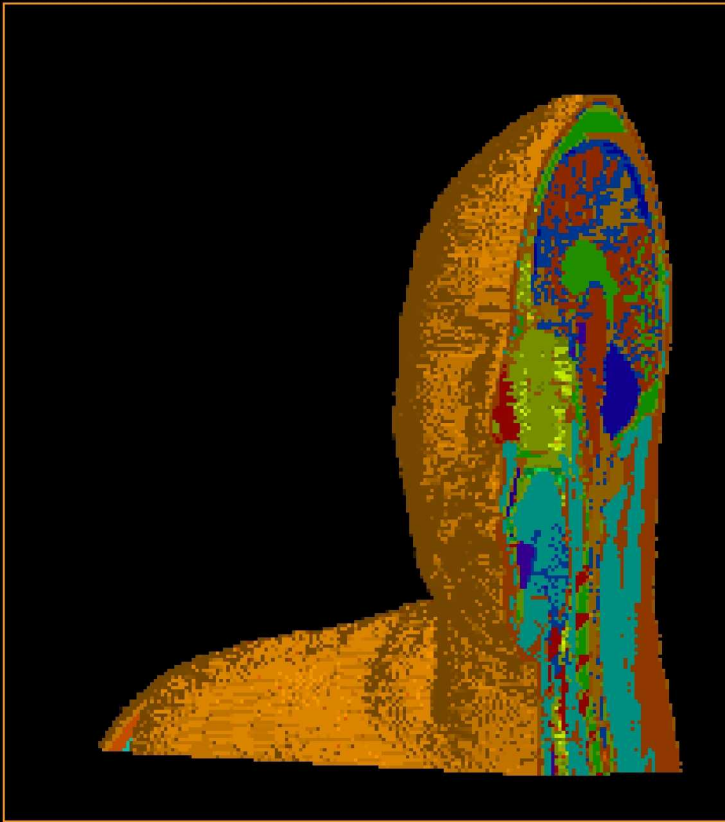


Naval Health Research Center Detachment Directed Energy Bio-Effects Laboratory

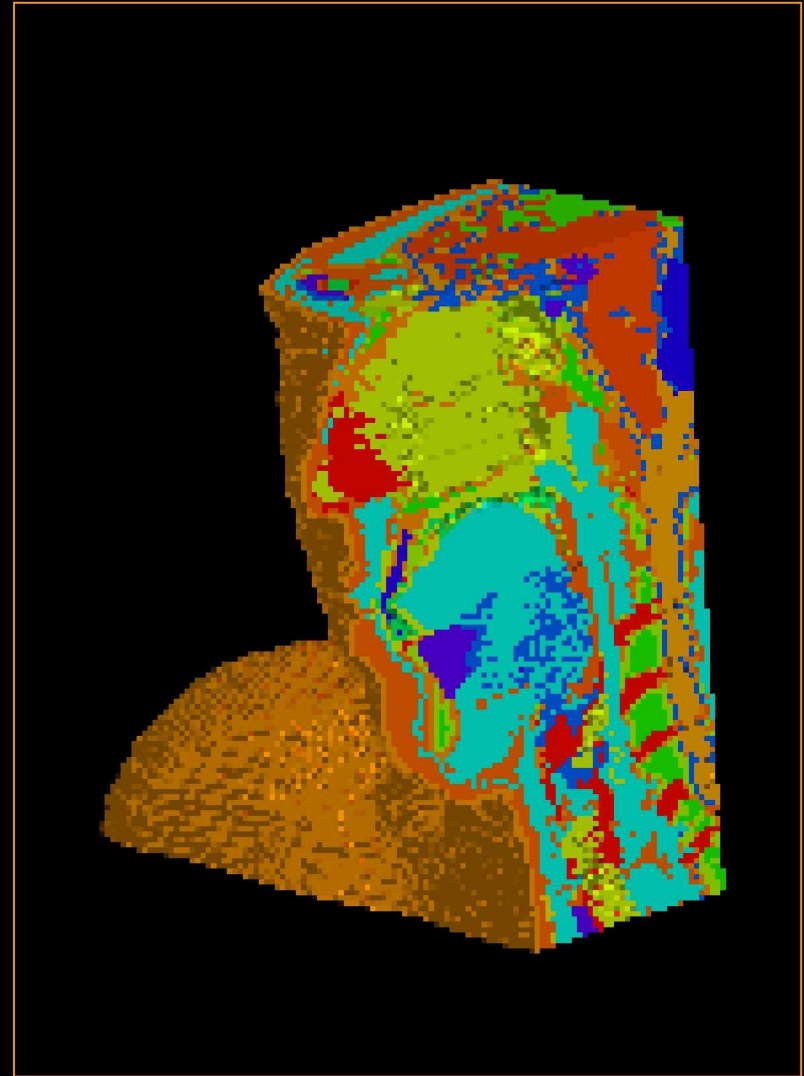


Cell Value	Color	Tissue Type
1		AIR (internal)
2		BILE
3		BODY FLUID
4		EYE (cornea)
5		FAT
6		LYMPH
7		MUCOUS MEMBRANE
8		NAILS (toe & finger)
11		NERVE (spine)
17		MUSCLE
25		HEART
30		WHITE MATTER
48		STOMACH
49		GLANDS
65		BLOOD VESSEL
68		LIVER
80		GALL BLADDER
100		SPLEEN
110		CEREBELLUM
111		BONE (cortical)
133		CARTILAGE
142		LIGAMENTS
143		SKIN/DERMIS
148		INTESTINE (large)
152		TOOTH
160		GRAY MATTER
163		EYE (lens)
164		LUNG (outer)
168		INTESTINE (small)
183		EYE (sclera/wall)
184		LUNG (inner)
188		PANCREAS
189		BLOOD
190		CEREBRAL SPINAL FLUID
203		EYE (retina)
204		EYE (aqueous humor)
207		KIDNEYS
209		BONE MARROW
227		BLADDER
228		TESTICLES
229		PERFECT CONDUCTOR
249		2/3 MUSCLE
250		PVC
251		FOAM
252		TEM (old)
253		BONE (cancellous)
254		TEM (new)
255		UTAH
		AIR(external)

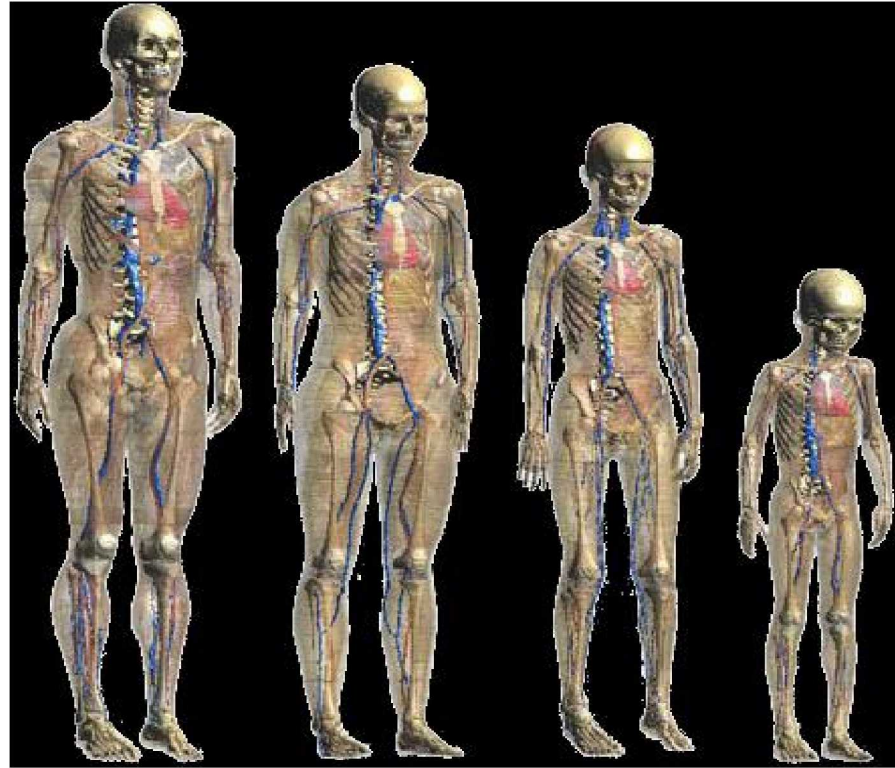
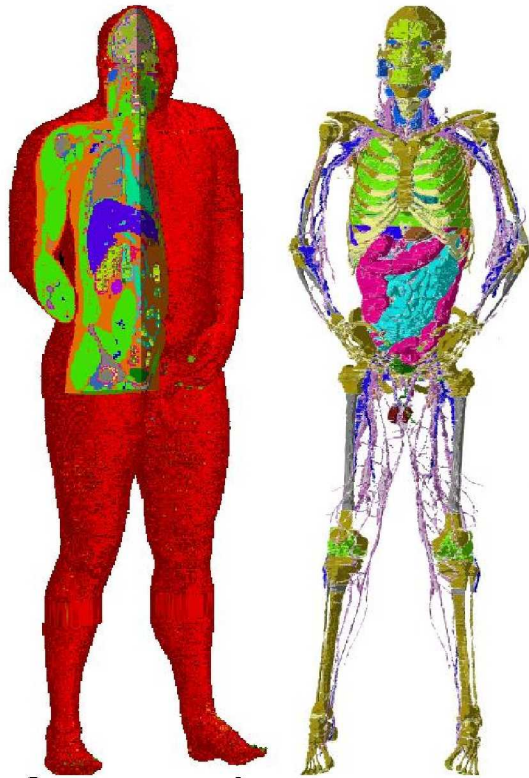
Models Created by Color Coding Images



Color coded 2D-images are combined to make solid volume electrical equivalent anatomical models



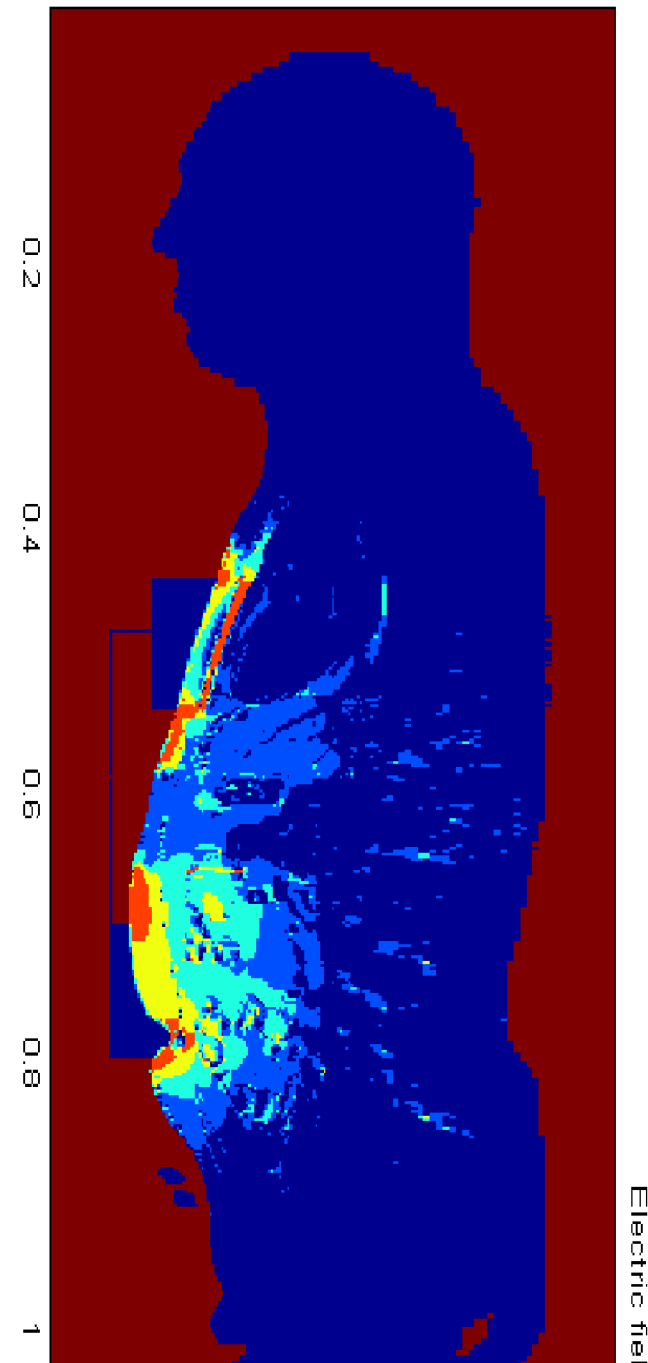
Impedance Models



- Left - Brooks Man anatomical model with a cutout (leftmost image) and with skin, fat and muscles removed (second image from left)
- Right - New human anatomical models including a 26-year-old female adult, a 34-year-old male adult, an 11-year-old female child, and a 6-year-old male child have become available (IT'IS Foundation, Zürich, Switzerland and sponsored by FDA)

Methods-1

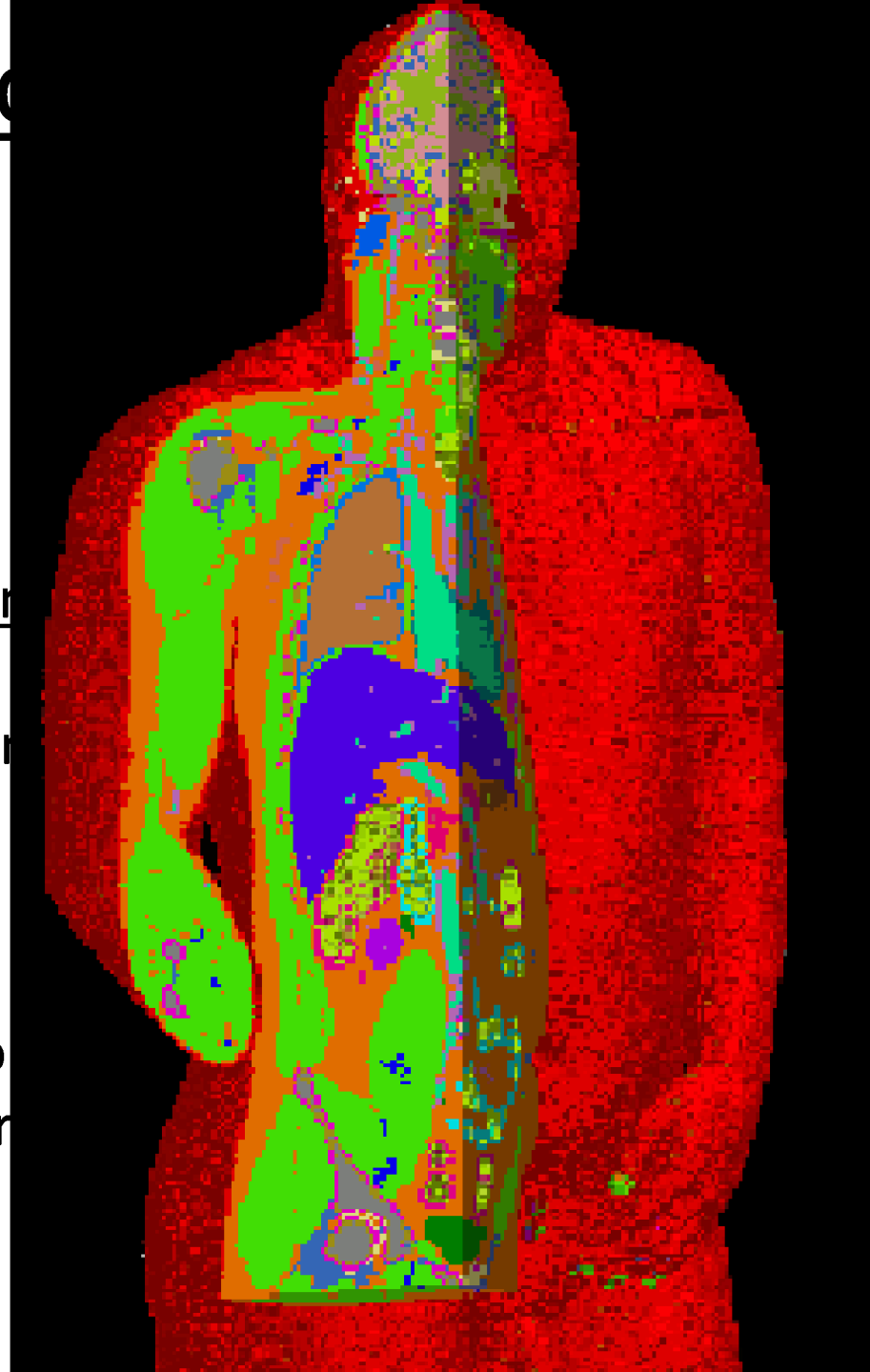
- Parametric analysis for very low voltage exposures (2 to 15 volts) could cause pain and/or involuntary muscle tetani or spinal cord shock.
- NASA is working with the **Naval Health Research Center Detachment Directed Energy Bioeffects** Laboratory to better characterize the physiological effects of these hazards using two models.
- For a pilot study, NASA requested analysis for only one exposure condition consisting of two metallic contacts, each having 100 cm² area, on the sweat-soaked chest and abdomen.



Method

The results of two computational models were combined to predict areas of the body in which neurons of different diameters would be excited.

1. Finite Difference Time Domain Model: calculates the distribution of electric fields in the human adult
2. Spatially Extended Nonlinear Node Model: establishes action potential thresholds for neurons of different diameter



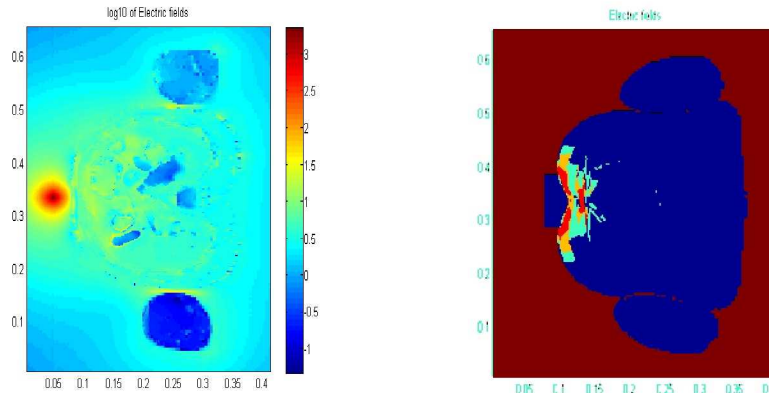
Naval Health Research Center Detachment Directed Energy Bio-effects Laboratory Pilot Study

Finite Difference Time Domain Model

The first computational model, which calculated the distribution of electric fields (E-fields) in the body, was the finite difference time domain (FDTD) model

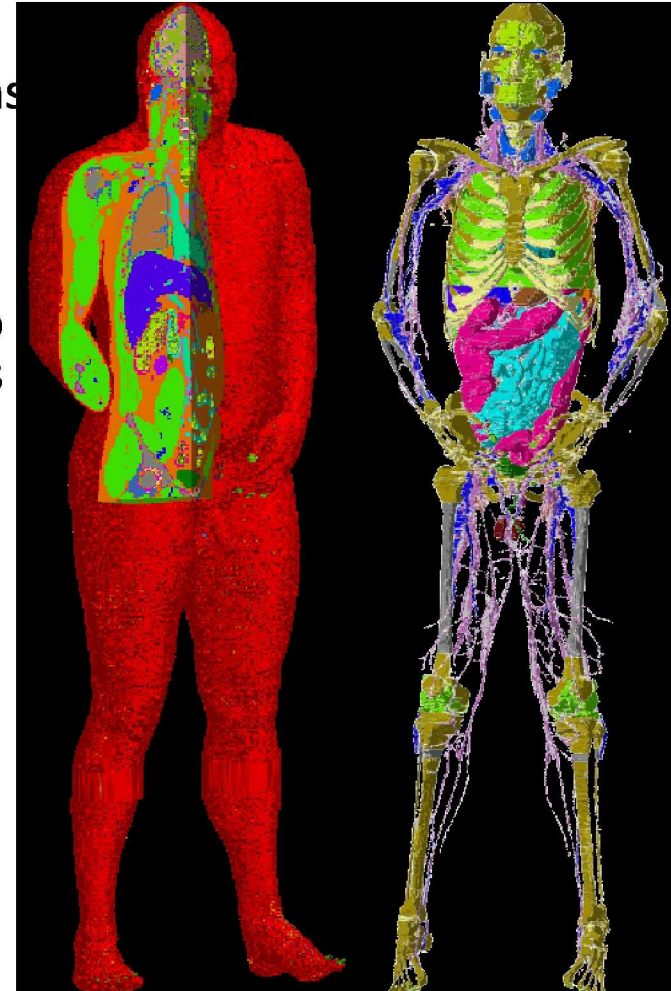
Spatially Extended Nonlinear Node Model

The second computational model, the Spatially Extended Nonlinear Node (SENN) model, was used to establish action potential (AP) thresholds for neurons of different diameters for the pulse parameters provided



**Convert calculated E-fields
into Nerve Action Potentials**

**Brooks Man anatomical model with a cutout (left image)
and with skin, fat and muscles removed (right image).**

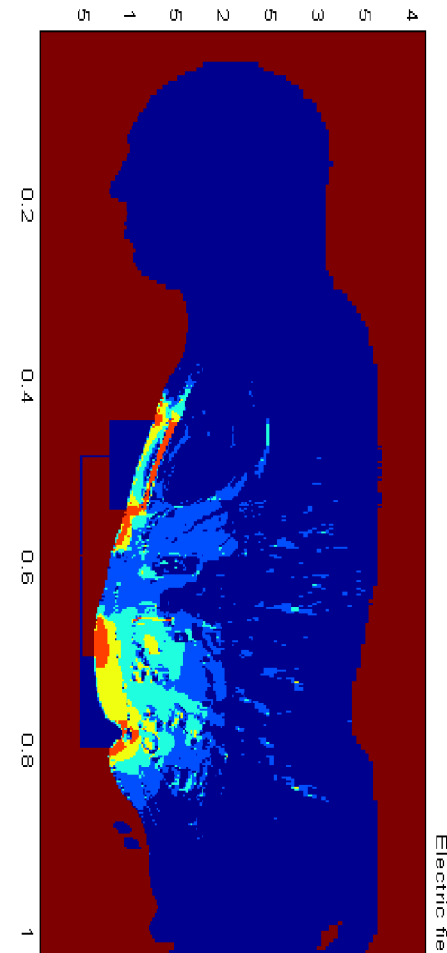


Naval Health Research Center Detachment Directed Energy Bio-effects Laboratory NASA Pilot Study – Initial Results

- The results of two computational models were combined to predict areas of the body in which neurons of different diameters would be excited
- To produce a rapid response to NASA's request, we considered only one exposure condition consisting of two metallic contacts, each having 100 cm² area, on the sweat-soaked chest and abdomen
- Given the increasing potential for exposure and the uncertainty surrounding the actual levels that may reach astronauts, SLSD does not feel that a conclusion of “no physiological effects” is supportable at this time
- Action Potential Thresholds (36.67 mA, 109 Ω: 7384 cm³ > 6.15 V/m AP Threshold)

Table 1: Rheobase thresholds for stimulating neurons of various diameters and color key to images of FDTD results below.		
Color	E-field (V/m)	Neuron diameter class (μm)
Orange	> 49.2	all
Yellow	24.6 ± 49.2	2.5 - 5
Sky blue	12.3 ± 24.6	5 - 10
Dark blue	6.15 ± 12.3	10 - 20
Very dark blue	< 6.15	none*
* A maximum diameter class of 20 μm and a minimum of 1.25 μm is assumed		

Midline sagittal plane of three-dimensional Finite Difference Time Domain analysis showing internal E-fields color coded according to thresholds for neural stimulation (See Table ± left)



Results

- The models predict that, for low voltage exposures in the space suit, physiologically active current could be conducted across the crew member causing **catastrophic hazards**.
- Future work with Naval Health Research Center Detachment Directed Energy Bio-effects Laboratory is being proposed to analyze additional current paths across the human torso and upper limbs.
- These models may need to be verified with human studies.



Questions

